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Long-Term Adaptation:

Selecting Farm Types across Agro-Ecological Zones in Africa

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Abstract

Using economic data from more than 8,500 household surveys across 10 African countries, this paper examines whether the choice of farm type depends on the climate and agro-ecological zone of each farm. The paper also studies how farm type choice varies across farmers in each zone, using a multinomial logit choice model. Farmers are observed to choose from one of the following five types of farms: rainfed crop-only, irrigated crop-only, mixed rainfed (crop and livestock), mixed irrigated, and livestock-only farming. The authors compare current decisions against future decisions as if the only change were climate change. They focus on two climate scenarios from existing climate models: the Canadian Climate Centre scenario, which is hot and dry, and the Parallel Climate Model scenario, which is mild and wet. The results indicate that the change in farm types varies dramatically by climate scenario but also by agro-ecological zone. Policy makers must be careful to encourage the appropriate suite of measures to promote the most adapted farm type to each location.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to mainstream research on climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at Niggol.seo@yale.edu, Robert.mendelsohn@yale.edu, Adinar@worldbank.org, Rashid.hassan@up.ac.za, and Pradeep.kurukulasuriya@undp.org.

LONG-TERM ADAPTATION: SELECTING FARM TYPES ACROSS AGRO-ECOLOGICAL ZONES IN AFRICA[1]

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1. Introduction

There is strong scientific evidence that the earth is warming due to greenhouse gas emissions into the atmosphere (IPCC 2007). Agriculture is expected to be one of the most vulnerable economic sectors to this climate change (Pearce et al. 1996; Reilly 2006; Tol 2002; Mendelsohn and Williams 2007). Agriculture in low-latitude developing countries is especially vulnerable because the majority of poor households depend on local farming and because the high current temperatures of many developing countries makes farming challenging. Consequently, the impact of climate change on agriculture has been one of the most studied impacts of climate change (Adams et al. 1990; Rosenzweig and Parry 1994; Mendelsohn et al. 1994; Reilly et al. 1996; Schlenker et al. 2005; Kurukulasuriya et al. 2007a, 2007b, 2008a, 2008b; Deschenes and Greenstone 2007; Seo and Mendelsohn 2008a, 2008b, 2008c, 2008d; Wang et al 2008).

Researchers agree that climate change will damage agriculture in developing countries, such as countries in Africa and South America (Rosenzweig and Parry 1994; Reilly et al. 1996; Kurukulasuriya et al. 2007; Seo and Mendelsohn 2007). But the magnitude of such damage will depend on how efficiently farmers adapt to the new climates (Mendelsohn 2000). As farmers make adjustments that increase their net revenue through efficient adaptations, they will reduce the potential damages from climate change. Initial research indicates that farmers are likely to make many changes including changing irrigation, crop species choice, and livestock species choice (Kurukulasuriya and Mendelsohn 2006; 2007, 2008; Seo and Mendelsohn 2008a; 2008b).

This study focuses on the choice of farm type as an adaptation to climate change (Mendelsohn and Seo 2007, Hassan and Nhemachena 2008). We extend earlier studies on adapting through farm type selection by looking at how this choice varies by Agroecological Zones (AEZs). Tying the choice to AEZs illustrates how the choice varies across the landscape and also allows us to extrapolate from our sample of farms to the continent.

The paper examines five farm types: crop-only rainfed, crop-only irrigated, mixed (crop and livestock) rainfed, mixed irrigated, and livestock-only farms. A multinomial logit model is estimated to predict the probability each farm type is chosen in each AEZ in

Africa. The analysis uses a dataset of 8500 household farms collected across 10 countries in Africa (Dinar et al., 2008).

This paper differs from previous adaptation papers in that it quantifies adaptation measures appropriate for each of the 16 Agro-Ecological Zones in Africa. Based on the AEZ classification by the FAO (1978), the paper examines the likelihood each farm type is adopted in each AEZ. Since a single adaptation policy is never relevant to all AEZs, it is important to quantify how adaptation measures vary across AEZs depending on agro-climatic conditions.

In the next section, a multinomial logit model of choice of farm type is provided. Data used in the study are described in the third section. The fourth section provides the empirical results. The paper then simulates climate change impacts on the distribution of farm types across AEZs for two climate scenarios in 2100, a hot and dry scenario and a mild and wet scenario. The paper concludes with discussions and policy implications.

2. Theory

We assume that farmers manage their farms to maximize the net revenue from various farming activities, taking the existing climate as given. We define net revenue broadly to include the value of own consumption. So the model provides an appropriate description of both commercial and household farms. Farmers first consider a type of farm and then which combination of crops or livestock species, inputs, and timing that would maximize the net revenue they obtain. We assume that farmers have five choices about the type of farm they can select: crop-only rainfed, crop-only irrigated, mixed (crop and livestock) rainfed, mixed irrigated, and livestock-only farms[7]. Farmers will examine exogenous factors relevant to their farm but beyond their control when making these decisions. Most specifically, they will consider climate but also soils and elevation. Because these factors determine which AEZ a farmer is in, we hypothesize that the farmers' choices will vary by AEZ.

Let the net revenue from these five alternative farm types, *j*, be written in the following

[7] The number of farms that specialized in livestock is too small to divide them into rainfed livestock only farms and irrigated livestock only farms. Most of them are, however, raise livestock on dryland.

form:

$$\pi_{jw} = V\ (Z_{jw}) + \varepsilon_{jw} \quad \text{where } \mathrm{j} = 1,...,5 \text{ and } \mathrm{w} = 1,...,16. \tag{1}$$

where Z is a vector of exogenous variables that affect profitability of any of the five types of farms and w reflects the 16 AEZs in Africa.. For example, Z includes climate, soils, water availability, market access variables, electricity provision, and education of the farmer. Note that farmers choose farm type j from the five alternatives, but they do not choose AEZ w. The profit function is composed of two components: the observable component V and an error term ε.

The decision of a farmer who is located in AEZ w, is to choose one farm type from the available choices j that yields the highest net revenue given the external conditions:

$$\arg\max_{j} \{\pi^*{}_{1w}, \pi^*{}_{2w}, ..., \pi^*{}_{Jw}\} \tag{2}$$

Suppressing the subscript w, the farmer will choose farm type j over all other farm types if:

$$\pi_j{}^* > \pi_k{}^* \text{ for } \forall\ \mathrm{k} \neq j. \quad [\text{or if } \varepsilon_k - \varepsilon_j < V\ (Z_j) - V\ (Z_k) \text{ for } \mathrm{k} \neq j] \tag{3}$$

The probability P_j for farm type j to be chosen is then

$$P_j = \Pr[\varepsilon_k - \varepsilon_j < V_j - V_k]\ \forall\ \mathrm{k} \neq j \quad \text{where } \mathrm{V_j} = \mathrm{V}\ (\mathrm{Z_j}) \tag{4}$$

Assuming that ε follows an identical and independent Type I Extreme Value distribution and that the profit can be written as a quadratic function of the variables, then the probability a farm type is chosen can be calculated as follows (McFadden 1981):

$$P_j = \frac{e^{Z_j \gamma_j + Z_j^2 \alpha_j}}{\sum_{k=1}^{J} e^{Z_k \gamma_k + Z_j^2 \alpha_k}} \tag{5}$$

We calculate the probability in Equation 5 for each AEZ and for each of the five farm types.

It is expected that farmers in a specific AEZ are more likely to choose a specific farm type than farmers in other AEZs. For example, in a dry savannah, we expect that farmers are more likely to choose farm types with some livestock, either mixed farms or livestock only farms due to a favorable climate condition to livestock (Seo and Mendelsohn 2008). Differentiating Equation (5) with respect to a climate variable Z_l yields:

$$\frac{\partial P_{jw}}{\partial z_l} = P_{jw}[\gamma_{lj} + 2Z_{lw}\alpha_{lj} - \sum_{k=1}^{J} P_{kw}[\gamma_{lk} + 2Z_{lw}\alpha_{lk}] \text{ for w} = 1,2,...,\text{W}. \quad (6)$$

The marginal impact of each climate variable on the probability of each farm type depends upon the climate in each AEZ. It therefore follows that farms in each AEZ will react differently to climate change even though the parameters of the model are not specific to an AEZ.

3. Description of Data

The paper uses a typology of Agro-Ecological Zones developed by the Food and Agriculture Organization as a mechanism to classify the crop potential of land (FAO 1978). The AEZs are defined using the length of the growing season. The length of the growing season, in turn, is defined as the period where precipitation and stored soil moisture is greater than half of the evapotranspiration during this period. The longer the growing season, the more crops can be planted (multiple seasons) and the higher are the yields (Fischer and van Velthuizen 1996; Vortman et al. 1999). FAO has classified land throughout Africa using this AEZ concept.

The economic data for this study were collected by the national teams in ten countries across Africa. South Africa and Zambia were sampled from Southern Africa, Kenya and Ethiopia were from East Africa, Senegal, Niger, Burkina Faso, Ghana, and Cameroon were from West Africa, and Egypt was chosen from North Africa. Data from Zimbabwe could not be used due to the political turmoil in that country during the survey period. In each country, districts were selected so that they represent a broad range of climates in that country. In each selected district, a survey was conducted of randomly selected farms. The sampling was clustered in villages to reduce sampling costs (Dinar et al. 2008). Once the surveys were cleaned, a total of 8500 observations remained.

The economic surveys were then matched with climate data. The temperature data come from a set of polar orbiting satellites operated by the US Department of Defense. This satellite data was chosen because it passes above each location on earth between 6am and 6pm every day (Basist et al. 2001). These satellites are equipped with sensors that measure surface temperature by detecting microwaves that pass through clouds. However, these satellites do not measure precipitation directly. Hence, the paper relied on the precipitation data of the Africa Rainfall and Temperature Evaluation System (ARTES) (World Bank 2003). This data set, created by the National Oceanic and Atmospheric Association's Climate Prediction Center, interpolates weather variables across Africa based on ground station measurements of precipitation.

Soil data from FAO (2003) were then matched with each observation. The FAO data provide information about major and minor soils in each location as well as slope and texture. Data concerning the hydrology were obtained from the University of Colorado (Strzepek and McCluskey 2006). Using a hydrological model for Africa, flow and runoff were calculated for each district in the surveyed countries. Data on elevation at the centroid of each district were obtained from the United States Geological Survey (USGS 2004). The USGS data are derived from a global digital elevation model with a horizontal grid spacing of 30 arc seconds (approximately one kilometer).

4. Empirical Results

FAO classified Africa into 16 AEZs, the distribution of which is shown in Figure 1. The Sahara desert occupies a vast land area in the north. There are also desert zones in the eastern and southern edge of the continent. Just beneath the Sahara in West Africa is a lowland semi-arid zone, followed by lowland dry savannah, lowland moist savannah, and a lowland sub-humid zone. The lowland humid forest then stretches from Cameroon across Central Africa. Eastern Africa is composed of some desert, lowland dry savannah, and some high elevation humid forest and high elevation dry savannah which are located around Mount Kilimanjaro and part of Kenya. Southern Africa consists of lowland or mid elevation moist savannah, and lowland or mid elevation dry savannah.

As each AEZ is endowed with unique agro-ecological resources, we expect that certain farm types, as defined in the previous section, are more likely in certain AEZs.[8] In the sample, shown in Table 1, crop-only farms were chosen widely in low elevation humid forest, mid elevation humid forest, and high elevation humid forest. Farmers irrigated most often when they are in deserts, high elevation dry savannah, high elevation semi-arid, and mid elevation semi-arid AEZs. Livestock-only farms are chosen more often in the mid elevation semi-arid AEZ. Mixed farms are chosen widely across all the AEZs except for lowland humid forest and mid elevation semi-arid AEZs.

To test whether a statistical relationship between farm type distribution and climate exists, a multinomial logit regression of farm type choice over a set of climate variables and control variables was estimated. Livestock-only farming was omitted so it is the baseline choice to which the other choices are being compared. The results are presented in Table 2. Many of the climate coefficients are significant indicating that climate variables are significant determinants of the choice of farm types.

The other factors that were tested include soils, access to electricity, a regional dummy for West Africa, water flows, and crop prices. The results suggest that farms with access to electricity choose livestock-only farms more often. This may be due to the fact that electricity is essential for some livestock operations such as milking and cooling milk, but it may simply reflect a missing variable correlated with electricity. Soil variables are not significant implying they do not affect the choice of farm type although they do affect the productivity of farms. West African farms relied more on irrigation, either crop-only or mixed farm types. The coefficients on the West African regional dummy implies that West African farmers are much more likely to choose irrigated crop only and mixed farms relative to livestock only farms. This may be due to policies that encourage irrigation and the prevalence of livestock diseases that make raising livestock difficult in West Africa. The amount of water flowing into a district in each season was important in the decision making. When spring flow is high, farmers chose irrigation. On the other hand, when summer flow is high, they resorted to rainfed crops. Crop prices also affected the choice. When the price of maize, a typical grain in Africa, is high, farmers tended to

[8] We recognize that there are more farm types than identified in our analysis. However, our data allowed us to specify only five farm types, but these consistently cover the range of farming activities in Africa.

choose rainfed farms relying on natural rainfall[9]. However, when the price of millet which is used for both human food and livestock feed is high, farmers tended to choose livestock-only farms[10]. Other control variables such as age and gender of the head of the farm, household size, and culture were tested but dropped because they were not significant.

Based on the estimated parameters in Table 2, the current probability of each farm type for each of the 16 AEZs was calculated in Table 3. The table also presents the marginal impact of climate change on these probabilities. For example, the marginal impact of warming is shown as the change in the probability of a farm type in response to one °C increase in temperature and the marginal impact of more rain is the change in probability in response to one mm/mo increase in precipitation. Crop-only rainfed farms are chosen most often in sub-humid, humid forest, moist savannah in both high elevation and mid elevation. As temperature warms, farmers tend to shift away from crop-only rainfed farming in each AEZ. But when rainfall increases by 1 mm/month, they increase the chance of adopting crop-only rainfed farming. Mixed rainfed farms are chosen most often in dry savannah and semi-arid AEZs in high elevation and mid elevation. As temperature increases, farmers choose this farm type more often when they are located in high elevation or mid elevation AEZs. But they choose it less often when the farm is located in lowland AEZs. Farmers also choose this farm type more often when rainfall increases except in lowland AEZs and mid elevation dry savannah.

Crop-only irrigated farms are chosen most often in the desert, lowland dry savannah, and lowland semi-arid. If rainfall increases, then farmers shift away from this farm type and rely more on natural rainfall. If temperature increases, farmers also reduce this farm type except in deserts. Farmers may continue to choose crop-only irrigated farms in deserts even with warming because deserts cannot support rainfed agriculture. Mixed irrigated

[9] There are many places in which maize is grown with irrigation system. However, most maize producing and consuming regions fall in relatively humid zones where irrigation is not needed in which case farmers rely on rainfed farming. It is likely that irrigation decision depends more on other grains than maize, but maize is most widely chosen across Africa and seems to represent rainfed farms most successively.

[10] Many grains other than millet are suitable for livestock feed. But millet is grown for livestock widely around the world.

farms are chosen more often in desert, lowland dry savannah, and lowland semi-arid AEZs. However, with warming, farmers increase their use of this farm type across all the AEZs. If precipitation increases, farmers reduce this farm type across all the AEZs. Livestock-only farms are chosen more often in the desert and mid elevation semi-arid AEZs. An increase in rainfall reduces the chance this farm type is chosen across all the AEZs. Cattle and sheep which are major commercial livestock are raised in drier places (Seo and Mendelsohn 2008). Warming increases the chance of livestock-only farms to be chosen in high elevation and mid elevation AEZs, but not in lowland AEZs. Farmers choose to have livestock when climate turns too hot for crops (Seo and Mendelsohn 2008).

5. Climate Change Predictions

Using the empirical model of farm type choice in the previous section, we predict how future climate scenarios may affect the future distribution of each farm types across each AEZ. We explore two distinctly different future climate predictions for 2100: the CCC (Canadian Climate Centre) scenario (Boer et al. 2000) and the PCM (Parallel Climate Model) scenario (Washington et al. 2000). These two scenarios reflect the range of outcomes predicted in the most recent IPCC (Intergovernmental Panel on Climate Change) report (IPCC 2007). In each of these scenarios, climate changes at the grid cell level were summed with population weights to predict climate changes by country. We then examined the consequences of these country level climate change scenarios for 2100.

To obtain district level climate predictions for each scenario, we added the predicted change in temperature from the climate model to the baseline temperature for each season in each district. For precipitation, we multiplied the predicted percentage change in precipitation from the climate models by the baseline precipitation for each season in each district. Table 4 presents the African mean temperature and rainfall predicted by the two models for each season for the year 2100. Across all African countries in 2100, PCM predicts an average increase of 2°C increase while CCC predicts an average increase of 6.5°C increase in annual mean temperature. PCM predicts an average 10% increase in annual mean rainfall in Africa but CCC predicts an average 15% decrease. So the PCM scenario is mild and wet whereas the CCC scenario is hot and dry. Even though the annual mean rainfall in Africa is predicted to increase/decrease depending on the scenario, there is substantial variation in rainfall across countries. However, both models predict summer rainfall to decrease while winter rainfall to increase.

Based on the parameter estimates in Table 2 and climate scenarios in Table 4, the paper calculates the probability of each of the five farm types in each of the 16 AEZs. Table 5 shows the predicted current probability and the change in probability caused by each climate scenario. Crop-only rainfed farms declines under the CCC scenario in all the AEZs, except in lowland dry AEZs. On the other hand, under the PCM scenario crop-only rainfed farms increase in all the AEZs except for the currently wet zones in low, mid, and high elevations. Crop-only irrigated farms increase in high elevation and mid elevation AEZs under the CCC scenario, except in lowland AEZs. The change in frequency of crop-only irrigated farms is very mixed under the PCM scenario, increasing in half of the AEZs and falling in half of the AEZs.

The choice of mixed farms is quite different from the choice of crop-only farms. Under the CCC scenario, rainfed mixed farms decrease in most AEZs except in sub-humid, moist savannah, and humid forests. Under PCM, most farmers turn to mixed rainfed farms, except in the desert, high elevation dry savannah, and high elevation semi-arid AEZs. Mixed irrigated farms are more resilient to higher temperature. This farm type increases across all the AEZs under the CCC scenario except in mid and high mid elevation humid forests. With the increased moisture of the PCM scenario, however, farmers reduce their reliance on mixed irrigated farms across all the AEZs except for the desert.

Under the CCC scenario, livestock-only farms decline in all the AEZs except humid forests and moist savannahs at both mid and high elevations. Livestock can endure higher temperatures when they are raised in high elevations with enough moisture. Livestock-only farms decline in all 16 AEZs under the PCM scenario. Livestock performance declines if conditions are too wet partly due to livestock diseases in Africa.

We extrapolate the results from the sample to all of Africa using the distribution of AEZs. The results are presented in Figures 2-6 for each type of farm. Crop-only rainfed farms decline under the CCC except in the deserts but increases under the PCM scenario except at high elevations (Figure 2). Crop-only irrigated farms increase across Africa under the CCC scenario unless the region is currently very wet (Figure 3). With the PCM scenario, crop only irrigated farms also fall in southern Africa.

Mixed rainfed farms increase under the CCC scenario except that regions close to the deserts see little change (Figure 4). Mixed rainfed farms increase over most of Africa under the PCM scenario except in the deserts. Mixed irrigated farms, on the other hand, increase across the continent under the CCC scenario except where rainfall is high (Figure 5). The figure clearly indicates that having both irrigated crops and livestock will be preferred in the future when climate turns hot and dry. Mixed irrigated farms largely fall under the PCM scenario as farmers take advantage of the higher natural rainfall and move away from irrigated crops.

Under the CCC scenario, farmers make few changes in livestock-only farms in lowland and mid elevation (Figure 6). However, farmers increase livestock-only farms in high elevations in this hot and dry scenario. Livestock only farms are reduced slightly across all AEZs under the PCM scenario.

6. Conclusions and Policy Implications

This paper examines the distribution of farm types as a long-term adaptation strategy to climate change. The paper specifically looks at the choice of farm type across climate zones and explores how farmers choose farm type in each AEZ. The analysis of farm type reveals that farmers' choice is indeed climate sensitive. Farmers across Africa have adapted to their current climate condition by altering farm type that have been chosen. Climate variables are significant determinants of the choice of farm types, along with other variables such as electricity, soils, water flows, and crop prices.

These results suggest that future climate change will shift the distribution of farm types across Africa. We use the model estimated in the paper to predict how climate might influence the future distribution of farm types. Crop-only rainfed farms are currently chosen most often in wet areas in both high elevation and mid elevation. Warming will encourage farmers to reduce their use of this farm type but increased precipitation will encourage them to increase crop-only rainfed farms. Mixed rainfed farms are chosen most often in dry savannah and semi-arid AEZs in high elevation and mid elevation. As temperatures increase, farmers in high or mid elevation will choose this farm type more often but lowland farmers will choose it less often. As rainfall increases, farmers will increase the use of mixed rainfed farms in all but the lowland AEZs. Irrigated farms, both crop-only and mixed, are chosen most often in the desert, lowland dry savannah, and lowland semi-arid. If rainfall increases, then farmers will shift away from irrigated farms and rely more on natural rainfall. If temperature increases, farmers will also reduce their reliance on crop-only irrigated farms except in desert areas. Unlike crop-only irrigated farms, farmers across all the AEZs choose mixed irrigated farms more often if temperatures increase. Livestock-only farms are preferred by farmers in the desert and mid elevation semi-arid AEZs. An increase in rainfall reduces the chance of this farm type but an increase in temperature increases the chance of livestock farms in mid and high elevations but not in the lowlands.

The paper provides a projection of the likely distribution of farm types in 2100 for two different climate scenarios, a hot and dry (CCC) scenario and a mild and wet (PCM) scenario. Crop-only rainfed farms decline under the CCC scenario in all the AEZs except dry lowland AEZs. Under the PCM, this farm type increases in all the AEZs except wet areas. Irrigated crop-only farms will increase under the CCC scenario if they are not in lowlands. Irrigated crop-only farms have very mixed responses under the PCM scenario, increasing in half, and falling in the other half of AEZs. . Mixed rainfed farms decline under the CCC scenario in most AEZs, except sub-humid, moist savannah, and humid forest AEZs. Under the PCM scenario, mixed rainfed farms increase except in the desert, high elevation dry savannah, and high elevation semi-arid AEZs. Mixed irrigated farms will increase under the CCC scenario except in humid forests at high elevation. But mixed irrigated farms will decline under the PCM scenario except in the desert. Under the CCC scenario, livestock-only farms decline in all the AEZs except in humid forest and moist savannah in mid and high mid elevations. Farms with only livestock decline in all the 16 AEZs when climate changes under the PCM scenario.

The results provide strong evidence that farmers will adapt to climate change by altering farm type. This adaptation will be quite complex depending on the climate scenario and the location of each farm. Government and development institutions must be careful intervening in this process that they carefully fit their intervention to what is needed locally. Uniform policies across all AEZs in Africa may have undesirable outcomes. By taking the observed preferences of farm types by profit maximizing farmers in each AEZ (that also cross countries), we actually integrate the impact of various existing policies across countries. Policy makers can design policies that support certain farm type selection as climate changes for each AEZ. Having the likelihood of selecting a given farm type in each of the AEZs across Africa, policy makers can anticipate desired changes and can prepare policy packages that would provide farmers incentives to move to certain farm types as climate changes, so that they maximize their future profits.

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Table 1: Number of Farms of Each Type by AEZ

Farm Type	Number AEZ 1	Percentage Desert	Number AEZ 9	Percentage Lowland moist Savannah
Crop-only Rainfed	40	4.0	544	25.1
Crop-only Irrigated	385	38.1	53	2.4
Mixed Rainfed	54	5.4	1208	55.7
Mixed Irrigated	410	40.6	158	7.3
Livestock Only	121	12.0	207	9.5
Farm Type	AEZ 2	High elevation dry savanna	AEZ 10	Lowland semi-arid
Crop-only Rainfed	9	7.7	189	26.7
Crop-only Irrigated	29	24.8	86	12.1
Mixed Rainfed	15	12.8	229	32.3
Mixed Irrigated	61	52.1	164	23.1
Livestock Only	3	2.6	41	5.8
Farm Type	AEZ 3	High elevation humid forest	AEZ 11	Lowland sub-humid
Crop-only Rainfed	316	33.5	487	37.8
Crop-only Irrigated	77	8.2	26	2.0
Mixed Rainfed	329	34.9	609	47.2
Mixed Irrigated	191	20.2	75	5.8
Livestock Only	31	3.3	93	7.2
Farm Type	AEZ 4	High elevation moist savannah	AEZ 12	Mid-elevation dry savannah
Crop-only Rainfed	70	19.0	218	23.5
Crop-only Irrigated	87	23.6	108	11.6
Mixed Rainfed	61	16.6	350	37.7
Mixed Irrigated	131	35.6	191	20.6
Livestock Only	19	5.2	61	6.6
Farm Type	AEZ 5	High elevation semi-arid	AEZ 13	Mid-elevation humid forest
Crop-only Rainfed	4	5.5	414	41.8
Crop-only Irrigated	20	27.4	42	4.2
Mixed Rainfed	3	4.1	359	36.3
Mixed Irrigated	41	56.2	137	13.8
Livestock Only	5	6.9	38	3.8
Farm Type	AEZ 6	High elevation sub-humid	AEZ 14	Mid-elevation moist savannah
Crop-only Rainfed	159	19.7	583	28.7
Crop-only Irrigated	148	18.3	167	8.2
Mixed Rainfed	158	19.5	892	43.9

Mixed Irrigated	309	38.2	287	14.1
Livestock Only	35	4.3	103	5.1
Farm Type	AEZ 7	Lowland dry savannah	AEZ 15	Mid-elevation semi-arid
Crop-only Rainfed	876	31.1	8	5.3
Crop-only Irrigated	121	4.3	27	18.0
Mixed Rainfed	1482	52.7	9	6.0
Mixed Irrigated	207	7.4	60	40.0
Livestock Only	128	4.6	46	30.7
Farm Type	AEZ 8	Lowland humid forest	AEZ 16	Mid-elevation sub-humid
Crop-only Rainfed	701	56.3	274	26.1
Crop-only Irrigated	22	1.8	112	10.7
Mixed Rainfed	488	39.2	292	27.8
Mixed Irrigated	7	0.6	316	30.1
Livestock Only	28	2.3	56	5.3

Table 2: Multinomial Logit Model of Farm Type Choice

	Crop Only Rainfed		Crop Only Irrigated	
	Est.	Chisq	Est.	Chisq
Intercept	9.8332	17.57	12.2474	22.53
Summer Temperature	-0.9496	34.34	-1.0552	30.43
Summer Temperature^2	0.0205	41.32	0.0202	27.58
Summer Precipitation	0.000783	0.02	-0.032	27.41
Summer Precipitation^2	0.000017	0.65	0.000109	20.34
Winter Temperature	0.2166	1.64	0.3508	4.27
Winter Temperature^2	-0.00576	1.56	-0.00593	1.53
Winter Precipitation	0.0401	22.02	-0.0395	13.13
Winter Precipitation^2	-0.00011	2.73	0.000118	2.16
Electricity	-0.5018	24.96	-0.5153	16.34
Soils Fluvisols	-2.0517	0.38	0.0608	0.00
Soils Luvisols	2.554	1.91	-0.7417	0.10
Soils Verisols	0.6339	0.16	-1.1027	0.33
West Africa	-0.1421	1.00	1.9576	96.11
Maize price	0.5053	0.38	-1.5864	1.81
Flow spring	-2.5554	19.51	1.1496	2.77
Flow summer	0.6484	12.09	-0.3352	2.07
Millet price	-0.9469	1.42	-4.2884	14.64

	Mixed Rainfed		Mixed Irrigated	
	Est.	Chisq	Est.	Chisq
Intercept	6.228	7.33	12.0479	24.22
Summer Temperature	-0.5689	12.7	-1.0185	32.64
Summer Temperature^2	0.0128	16.56	0.0196	30.28
Summer Precipitation	0.00314	0.39	-0.0287	23.99
Summer Precipitation^2	-6.48E-06	0.1	0.000118	25.2
Winter Temperature	0.1727	1.11	0.2678	2.53
Winter Temperature^2	-0.00451	1.01	-0.00266	0.32
Winter Precipitation	0.0261	9.55	-0.0306	5.89
Winter Precipitation^2	-0.00005	0.66	-0.00007	0.35
Electricity	-0.1493	2.24	-0.2572	4.46
Soils Fluvisols	-0.6993	0.05	0.5347	0.01
Soils Luvisols	2.2815	1.54	-3.1049	1.09
Soils Verisols	0.0791	0	-3.4594	1.92
West Africa	-0.0484	0.12	2.0108	120.02
Maize price	0.9189	1.33	-6.4615	27.62
Flow spring	-2.6163	20.65	1.2516	3.83
Flow summer	0.6339	11.6	-0.3235	2.27
Millet price	-0.6122	0.62	-1.1394	1.3

Note: N=7965. Likelihood Ratio= 5968.22 ($P<0.0001$)

Table 3: Marginal Climate Effects on the Probability of Each Farm Type (% per ˚C or % per mm/mo)

Type		AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8
Crop-only Rainfed	Current %	8.73	29.00	50.85	40.90	28.49	43.54	17.32	36.99
	Δ Temp	0.13	-0.94	-2.49	-1.85	-1.25	-2.10	-0.33	-1.36
	Δ Prec	0.05	0.14	0.26	0.19	0.12	0.28	0.09	0.30
Crop-only Irrigated	Current %	20.83	5.43	2.11	3.98	6.47	4.43	20.18	6.13
	Δ Temp	0.46	-0.14	-0.09	-0.15	-0.22	-0.16	-0.49	-0.22
	Δ Prec	-0.06	-0.08	-0.04	-0.06	-0.11	-0.06	-0.09	-0.06
Mixed Rainfed	Current %	18.64	52.08	41.50	45.55	51.18	42.06	25.58	43.44
	Δ Temp	-0.05	0.69	2.22	1.64	1.03	1.86	-1.09	1.08
	Δ Prec	0.05	0.02	-0.16	-0.08	0.10	-0.15	0.07	-0.17
Mixed Irrigated	Current %	34.98	7.34	3.40	6.14	7.61	6.69	35.51	10.49
	Δ Temp	1.11	0.23	0.03	0.06	0.09	0.06	2.08	0.33
	Δ Prec	-0.08	-0.06	-0.03	-0.04	-0.10	-0.04	-0.06	-0.04
Livestock-only	Current %	16.82	6.15	2.13	3.44	6.26	3.29	1.42	2.95
	Δ Temp	-1.65	0.16	0.33	0.30	0.35	0.34	-0.17	0.18
	Δ Prec	0.03	-0.02	-0.03	-0.03	-0.01	-0.03	0.00	-0.03
		AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Crop-only Rainfed	Current %	26.08	14.80	28.70	37.98	53.41	43.62	27.19	44.62
	Δ Temp	-0.47	-0.14	-0.95	-0.92	-2.42	-1.32	-0.76	-1.99
	Δ Prec	0.10	0.10	0.23	0.15	0.34	0.16	0.12	0.29
Crop-only Irrigated	Current %	13.19	18.17	8.14	3.80	1.27	2.54	5.63	3.30
	Δ Temp	-0.06	-0.59	-0.21	-0.08	-0.05	-0.07	-0.12	-0.11
	Δ Prec	-0.10	-0.09	-0.09	-0.06	-0.02	-0.03	-0.09	-0.05
Mixed Rainfed	Current %	37.05	25.02	42.16	49.88	41.20	47.68	52.41	43.85
	Δ Temp	-0.72	-0.86	0.29	0.78	2.16	1.19	0.72	1.70
	Δ Prec	0.04	0.08	-0.03	-0.01	-0.28	-0.10	0.07	-0.19
Mixed Irrigated	Current %	21.26	38.39	17.59	5.00	2.17	3.68	7.47	5.31
	Δ Temp	1.49	1.86	0.88	0.21	0.03	0.09	0.23	0.10
	Δ Prec	-0.03	-0.09	-0.08	-0.06	-0.01	-0.01	-0.08	-0.02
Livestock-only	Current %	2.42	3.63	3.41	3.34	1.94	2.48	7.30	2.93
	Δ Temp	-0.25	-0.27	-0.01	0.01	0.28	0.11	-0.08	0.29
	Δ Prec	-0.01	0.00	-0.02	-0.01	-0.03	-0.02	-0.02	-0.03

Table 4: AOGCM Climate Scenarios

	Current	2100
Summer Temperature (°C)		
CCC	25.7	+6.0
PCM	25.7	+2.2
Winter Temperature (°C)		
CCC	22.4	+7.3
PCM	22.4	+3.1
Summer Rainfall (mm/month)		
CCC	149.8	-33.7
PCM	149.8	-4.7
Winter Rainfall (mm/month)		
CCC	12.8	+3.5
PCM	12.8	+21.6

Table 5: The Changes in Farm Type Choice by AOGCM's by 2100 (in %)

Farm Type		AEZ1	AEZ2	AEZ3	AEZ4	AEZ5	AEZ6	AEZ7	AEZ8
Crop-only Rainfed	Current %	8.73	29.00	50.85	40.90	28.49	43.54	17.32	36.99
	Δ CCC	0.71	-6.05	-11.9	-9.45	-6.68	-11.8	10.55	-4.83
	Δ PCM	0.57	18.81	-6.25	11.92	19.68	3.50	5.21	4.56
Crop-only Irrigated	Current %	20.83	5.43	2.11	3.98	6.47	4.43	20.18	6.13
	Δ CCC	2.61	3.23	0.07	1.29	3.41	0.51	-9.00	-2.70
	Δ PCM	4.05	-5.30	4.03	-3.85	-6.35	-4.09	9.95	-2.85
Mixed Rainfed	Current %	18.64	52.08	41.50	45.55	51.18	42.06	25.58	43.44
	Δ CCC	-3.20	-3.45	10.15	4.42	-3.28	8.60	-4.29	8.80
	Δ PCM	-3.58	-1.24	6.81	0.54	-0.59	9.30	6.13	5.21
Mixed Irrigated	Current %	34.98	7.34	3.40	6.14	7.61	6.69	35.51	10.49
	Δ CCC	9.99	7.01	0.38	2.86	6.74	1.61	3.52	-1.06
	Δ PCM	9.25	-7.25	-3.11	-6.00	-7.56	-6.45	-20.3	-5.49
Livestock-only	Current %	16.82	6.15	2.13	3.44	6.26	3.29	1.42	2.95
	Δ CCC	-10.1	-0.74	1.30	0.88	-0.18	1.10	-0.77	-0.21
	Δ PCM	-10.2	-5.01	-1.48	-2.61	-5.18	-2.26	-0.95	-1.43
		AEZ9	AEZ10	AEZ11	AEZ12	AEZ13	AEZ14	AEZ15	AEZ16
Crop-only Rainfed	Current %	26.0	14.80	28.70	37.98	53.41	43.62	27.19	44.62
	Δ CCC	1.32	10.40	-0.73	-4.00	-13.3	-6.62	-3.77	-11.3
	Δ PCM	5.60	7.75	8.92	5.19	-3.88	-1.74	17.15	-1.97
Crop-only Irrigated	Current %	13.19	18.17	8.14	3.80	1.27	2.54	5.63	3.30
	Δ CCC	-3.32	-7.68	-3.52	1.25	-0.11	0.55	2.82	0.20
	Δ PCM	6.06	10.77	-5.40	-1.66	-0.84	4.93	-4.83	0.97
Mixed Rainfed	Current %	37.05	25.02	42.16	49.88	41.20	47.68	52.41	43.85
	Δ CCC	-5.84	-4.56	2.84	-0.77	12.47	4.39	-3.61	9.19
	Δ PCM	2.19	12.43	10.82	3.34	7.67	0.87	-1.00	8.22
Mixed Irrigated	Current %	21.26	38.39	17.59	5.00	2.17	3.68	7.47	5.31
	Δ CCC	9.07	3.58	2.38	4.25	-0.09	1.58	6.60	0.98
	Δ PCM	-12.2	-28.8	-12.3	-4.69	-1.69	-2.89	-6.26	-5.16
Livestock-only	Current %	2.42	3.63	3.41	3.34	1.94	2.48	7.30	2.93
	Δ CCC	-1.23	-1.73	-0.97	-0.74	1.12	0.11	-2.04	0.94
	Δ PCM	-1.57	-2.11	-1.97	-2.19	-1.26	-1.17	-5.06	-2.06

Fig 1: Agro-Ecological Zones of Africa

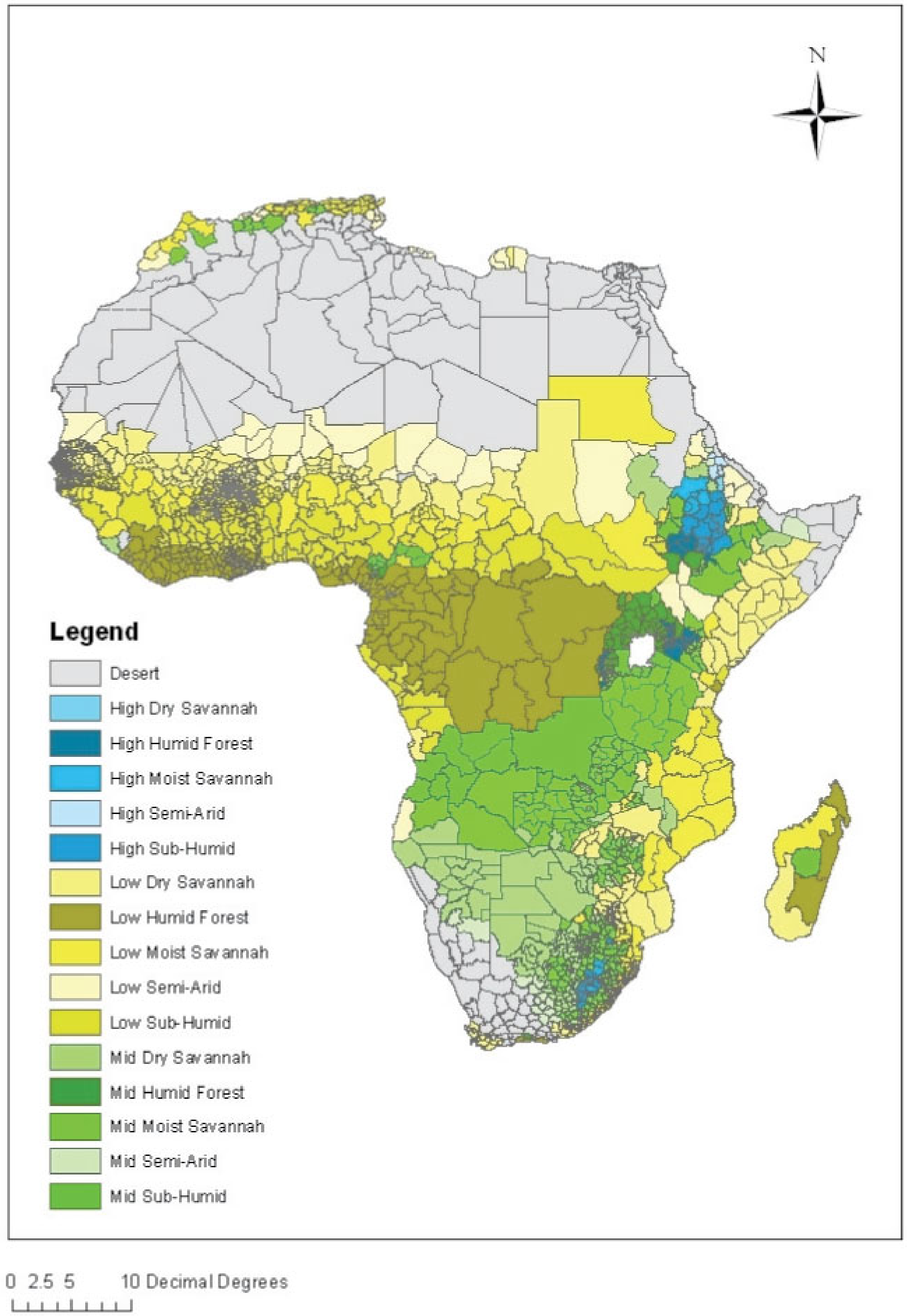
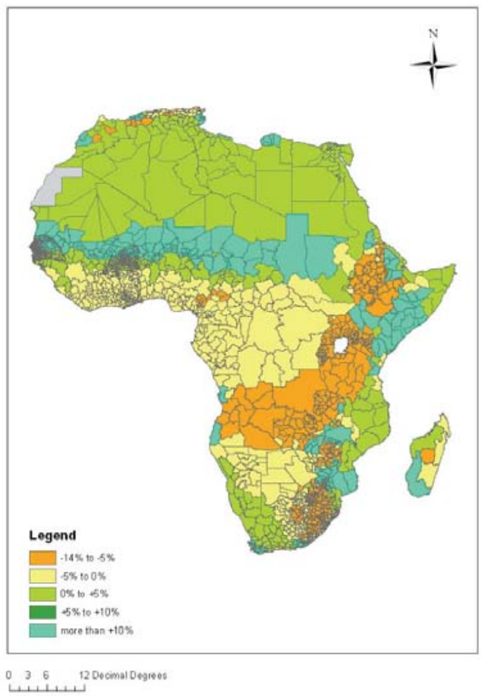


Fig 2: Crop-only Rainfed Farm Changes in Probabilities by CCC 2100 (Left), and by PCM 2100 (Right).



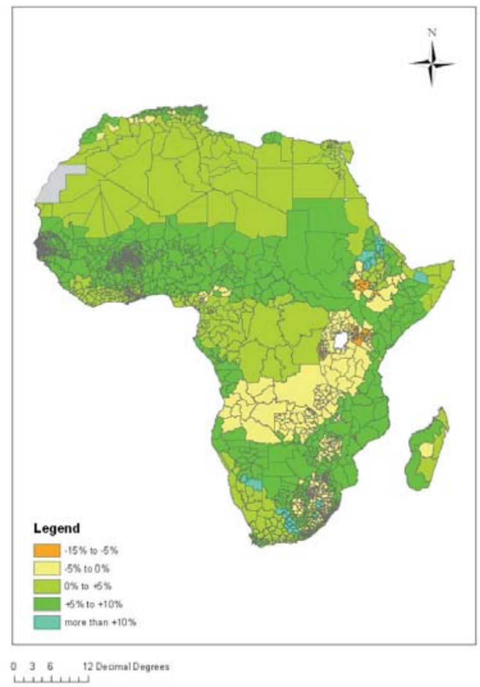
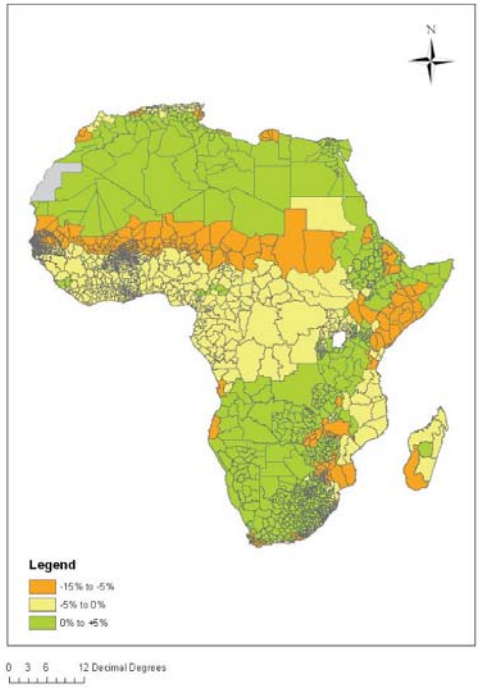


Fig 3: Crop-only Irrigated Farm Changes in Probabilities by CCC 2100 (Left), and by PCM 2100 (Right).



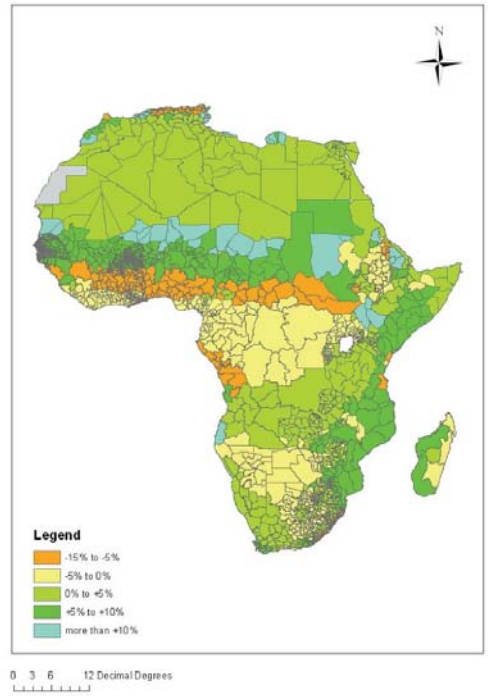


Fig 4: Mixed Rainfed Farm Changes in Probabilities by CCC 2100 (Left), and by PCM 2100 (Right).

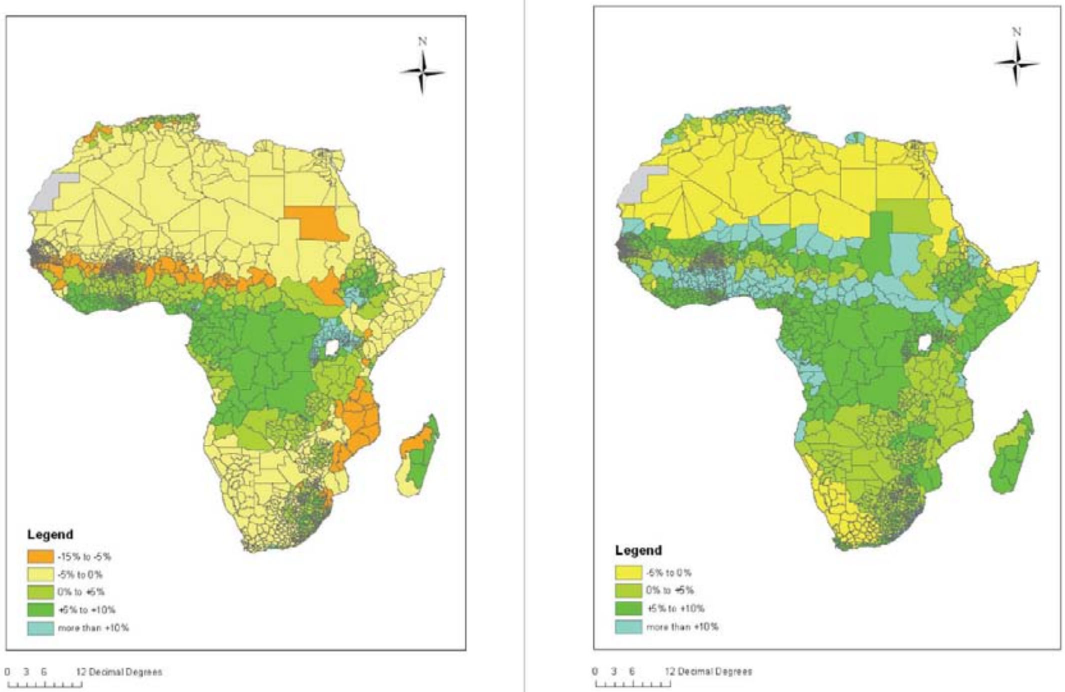


Fig 5: Mixed Irrigated Farm Changes in Probabilities by CCC 2100 (Left), and by PCM 2100 (Right).

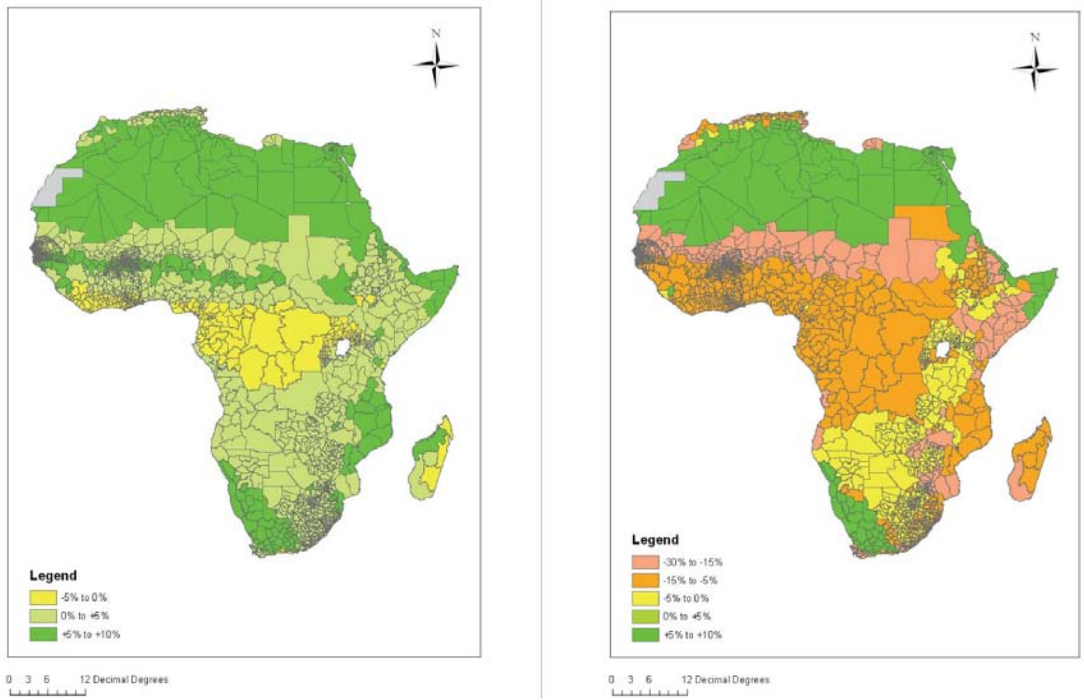


Fig 6: Livestock Only Farm Changes in Proba bilities by CCC 2100 (Left), and by PCM 2100(Right).